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(54) Title: WATERMARK DETECTION
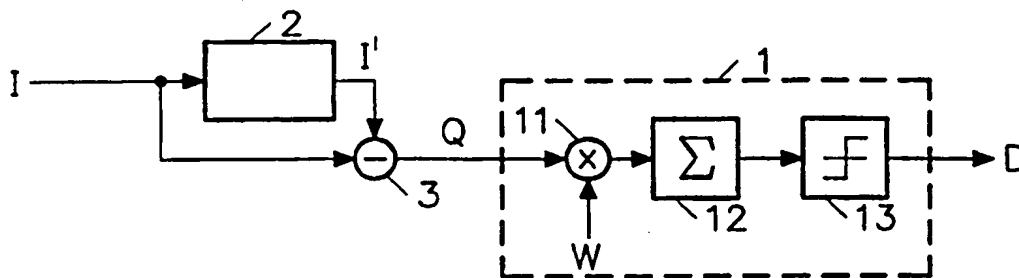
(57) Abstract

A watermark is assumed to be embedded in a suspect image if there is a given amount of correlation between the suspect image (I) and the watermark (W). The reliability of such a watermark detection method is considerably improved by distorting (2) the suspect image in such a way that a distorted image (I') is obtained which resembles the suspect image while the watermark is destroyed. The distorted image is then subtracted (3) from the suspect image to obtain a residual image (Q) in which the watermark is more dominant. The distortion may be a spatially-variant distortion such as stretching, shrinking, shearing or rotation. Embodiments are disclosed in which the distorted image is obtained by subjecting the suspect image to a non-linear transform or filter operation.

Watermark detection.

FIELD OF THE INVENTION

The invention relates to a method of detecting a watermark in a suspect image, comprising the steps of pre-processing the suspect image, determining the amount of correlation between the pre-processed image and the watermark, and generating a watermark

5   detection signal in dependence upon said amount of correlation. The invention also relates to a device for performing the method.

BACKGROUND OF THE INVENTION

A method of detecting a watermark as defined in the opening paragraph is

10   disclosed in International Patent Application WO-A 98/03014. As described in this Application, conventional watermark detection is based on determining the amount of correlation of a suspect image with the watermark to be detected. If the amount of correlation is less than a given threshold, the watermark is said to be absent, otherwise it is said to be present. The larger the correlation, the more reliable the detection and the more processing of

15   the watermarked image is allowed until the watermark cannot be detected anymore.

To improve the reliability of the watermark detection, the suspect image is pre-processed. In the prior-art watermark detection method, the pre-processing includes predictive or matched filtering of the suspect image prior to the conventional watermark detection. Such a matched filter is a convolution filter, i.e. the filtered image is a spatially-invariant linear

20   combination of global displacements of the same image. It is optimized to attenuate the frequencies for which the image dominates over the watermark. It works equally on the watermark and the underlying image.

SUMMARY OF THE INVENTION

25   It is an object of the invention to provide an improved method of detecting the watermark.

To this end, the method is characterized in that said pre-processing comprises the steps of subjecting the suspect image to a non-convolution filter operation so as to obtain a

distorted but resembling image which has less correlation with the watermark, and subtracting said distorted image from the suspect image.

A non-convolution filter is herein understood to mean a non-linear filter or a spatially-variant linear filter.

5   The invention is based on the recognition that most watermarking schemes are not resistant to (even minor) non-linear or spatially variant distortions. Such distortions do not necessarily affect the perceptual appearance of the image, but destroy the watermark information. The distorted image resembles the original image but has less correlation with the watermark. This property is here exploited to improve the reliability of the watermark

10   detection. By subtracting the distorted image from the suspect image, a difference image is obtained in which the ratio between the watermark information and the underlying residual image content is greatly enhanced. The performance of the subsequent conventional watermark detector is therefore considerably improved.

Examples of non-linear filters are median filters, local minimum filters and

15   local maximum filters. Examples of spatially variant operations are stretching, shrinking, shearing, rotation, motion compensation and region-based shifting. Various advantageous embodiments are defined in the appended claims and disclosed in the following description.

BRIEF DESCRIPTION OF THE DRAWINGS

20   Fig. 1 shows a schematic diagram of a device for performing the method of detecting a watermark in accordance with the invention.

Fig. 2 shows an embodiment of a device for detecting the watermark in accordance with the invention.

Figs. 3A-3C show diagrams to illustrate the operation of the device which is

25   shown in Fig. 2.

Figs. 4 and 5 show further embodiments of devices for detecting the watermark in accordance with the invention.

Figs. 6A-6C show diagrams to illustrate the operation of further embodiments of a distortion circuit shown in Fig. 1.

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DESCRIPTION OF EMBODIMENTS

Fig. 1 shows a device for detecting a watermark in a suspect image in accordance with the invention. The arrangement receives a suspect image I. Before applying the suspect image to a conventional watermark detector 1, the image is preprocessed by an

arrangement comprising a non-convolution filter 2 (hereinafter also referred to as distortion circuit) and a subtraction circuit 3 which subtracts the distorted image I' from the suspect image I. The difference image Q is applied to the conventional watermark detector 1.

The conventional watermark detector 1 comprises a multiplier 11, a summation
5   circuit 12 and a threshold circuit 13. The multiplier 11 and the summation circuit 12 constitute a correlation circuit. The multiplier receives the difference image Q and an applied watermark W. The watermark W is a matrix of data values w_{ij} that may have been added to the corresponding pixels p_{ij} of an image P in a perceptually unobtrusive manner.

The task of the device, which is shown in Fig. 1, is to detect whether the
10   suspect image I is watermarked (I=P+W) or not (I=P). To this end, the correlation circuit (11,12) calculates the inner product <Q,W> of the difference image Q and the watermark W, defined as:

$$< Q,W > = \frac{1}{N_1 N_2} \sum_{i=1}^{N_1} \sum_{j=1}^{N_2} q_{ij} w_{ij}$$

in which N_1 and N_2 are the width and height of the image in number of pixels, q_{ij} denotes the
15   pixel value of the difference image Q at position (i,j), and w_{ij} is the watermark data value at pixel position (i,j). It will be appreciated that, if the image signal is an analog signal, the summation circuit 12 will be an integrator.

The calculation of the correlation <Q,W> is often carried out in the Fourier domain. Because the dynamic range of the difference image Q in the Fourier domain is small,
20   the difference image can be represented by integers rather than floating point numbers. This reduces the hardware complexity considerably.

The output <Q,W> of the summation circuit 12 represents an amount of correlation between the input signal Q and the applied watermark W. The threshold circuit 13 determines whether said amount of correlation exceeds a predetermined threshold. If that is
25   the case, detection signal D=1 is generated to indicate the presence of the watermark. Otherwise the watermark is said to be absent (D=0).

Fig. 2 shows an embodiment of the watermark detection device in accordance with the invention. In this embodiment, the suspect image I is one of a sequence of images together constituting a motion video signal. The distortion circuit 2 comprises a motion
30   estimation circuit 21, a memory 22, and a motion compensation circuit 23. An earlier image of the sequence is available at the output of the memory 22. The earlier image (hereinafter referred to as reference image) may be the previous image or spaced a number of images apart. It may have the same watermark as the current image. The reference image and the current

image are applied to the motion estimation circuit **21**. Motion estimation is a well-known operation in the field of image coding and needs no detailed explanation. It suffices to mention that the motion estimation circuit **21** searches, for each image block of the current image I, the most resembling image block in memory **22**, and generates a motion vector mv indicating the relative position of the block thus found. It is important to note that the motion estimation is hardly affected by the embedded watermark, if any, because the image content is dominant.

The motion vectors mv and the reference image are then applied to the motion estimation circuit **23** to obtain a prediction for the current image. The prediction image I' resembles the current image but its watermark has been shaken up by the motion vectors. This is shown by way of example in Figs. 3A-3C. In Fig. 3A, the motion vectors generated by the motion estimation circuit **21** are shown as arrows. For example, motion vector **31** denotes that image block **33** of the reference image has been found to closely resemble image block **32** of current image I. Fig. 3B shows the watermark, which is the same in the current image and the reference image. For reasons of clarity, the watermark pattern is extremely simple in this example. Image content is not shown in the Figure although it dominates over the watermark in practice. Fig. 3C shows the prediction image I' generated by the motion compensation circuit. Image block **34** of this prediction image is the same as image block **33** of the reference image (see Fig. 3B) and thus resembles block **32** of the current image, but the watermark has been shifted. Again, the dominant image content is not shown in the Figure.

The difference image Q, obtained after subtracting the prediction image I' from the suspect image I can be written as:

$$Q = I - I'$$
$$= (P + W) - (P' + W')$$
$$= (P - P') + W - W'$$

in which P' and W' denote the motion-compensated image content and the motion-compensated watermark (cf. Fig. 3C), respectively.

In case of perfect motion estimation, the image residue (P-P') is very small, so that the correlation calculated by the watermark detector 1 can be approached by:

$$< Q, W > \approx < W, W > - < W, W' >$$

As can easily be understood with reference to Figs. 3B and 3C, the term <W,W'> which represents the correlation between the watermark W and its motion-compensated counterpart W' is low, provided that the motion vectors are sufficiently different. The correlation <Q,W> is thus mainly defined by the desired term <W,W>.

It should be noted that motion estimation (21), motion compensation (23), and subtracting (3) have often already been carried out at the encoding end of a video transmission chain. For example, MPEG encoded video signals include predictively encoded (P and B-) pictures. They are transmitted as residual images plus motion vectors. In view thereof, it will
5   be understood that a watermark in a received MPEG video signal can best be detected by subjecting the residual image to watermark detection.

The embodiment of the watermark detection device shown in Fig. 2 suffers from a reduced performance if there is no motion between the suspect image and the reference image (all motion vectors are zero). The performance is also reduced if large image areas are
10 subject to the same motion (all motion vectors are the same). Fig. 4 shows an embodiment of the device in which this problem is alleviated. The embodiment differs from the embodiment shown in Fig. 2 in that a circuit 24 for randomly modifying the motion vectors mv is inserted between the motion estimator 21 and the motion compensator 24. It is thereby achieved that the watermark W and its motion-compensated counterpart W' are decorrelated irrespective of
15 whether (large parts of) the image is subject to uniform motion or not. A disadvantage of randomizing the motion vectors is that the residual image content (P-P' in the formulas above) increases, even if the motion estimation is perfect. This can be solved, if necessary, by modifying the motion vectors only in image areas in which they are substantially zero or identical.

20   It has been found that the performance of the watermark detection is not dramatically affected by the motion vector randomization. This observation has led to a further embodiment which is shown in Fig. 5. In this embodiment, the motion estimation circuit has been omitted and replaced by a circuit 25 for randomly generating motion vectors. Not only is this embodiment cost-effective in view of the absence of an expensive motion estimator, it can
25 also be used to detect a watermark in isolated images without any reference to earlier images having the same watermark. To this end, the motion compensation circuit 23 receives the suspect image instead of an earlier reference image. In fact, the distortion circuit 2 in Fig. 5 generates a distorted image I' by randomly displacing regions of the suspect image I as shown in Fig. 3C.

30   Figs. 6A-6C show diagrams to illustrate further examples of spatially-variant linear filter operations carried out by the distortion circuit 2. In the Figs., the rectangle ABCD represents the suspect image I and the polygon A'B'C'D' represents the distorted image I'. In Fig. 6A. the distorted image is obtained by stretching (or shrinking if the image size is

decreased). In Fig. 6B, the distorted image is obtained by shearing. In Fig. 6C, the distorted image is obtained by rotation.

In a further embodiment of the device in accordance with the invention, the distortion filter 2 is a non-linear filter. An example of such a filter is a median filter. A median filter is a filter which receives a series of N input samples, re-arranges the series in order of decreasing or increasing values, and selects the middle sample of the re-arranged series. Here, a median filter is also understood to mean a filter which selects the nth (not necessarily the middle) sample of the series. It has been found that median filtering of a watermarked image yields a closely resembling image as far as image content is concerned, but largely destroys the embedded watermark. Thus, after subtracting the filtered image I' from the suspect image I, the image information is reduced and the watermark is retained. In the embodiment shown in Fig.6, the median filter is a 3*3 median filter. Each pixel of the suspect image is replaced by the median of the series comprising the original pixel and its eight neighboring pixels.

In summary, a watermark is assumed to be embedded in a suspect image if there is a given amount of correlation between the suspect image (I) and the watermark (W). The reliability of such a watermark detection method is considerably improved by distorting (2) the suspect image in such a way that a distorted image (I') is obtained which resembles the suspect image while the watermark is destroyed. The distorted image is then subtracted (3) from the suspect image to obtain a residual image (Q) in which the watermark is more dominant. The distortion may be a spatially-variant linear distortion such as stretching, shrinking, shearing or rotation, or a non-linear transform or filter operation.

CLAIMS:

1.   A method of detecting a watermark in a suspect image, comprising the steps of pre-processing (2,3) the suspect image, determining (11,12) the amount of correlation between the pre-processed image and the watermark, and generating (13) a watermark detection signal in dependence upon said amount of correlation, characterized in that said pre-processing (2,3) comprises the steps of subjecting the suspect image (I) to a non-convolution filter operation (2) so as to obtain a distorted but resembling image (I') which has less correlation with the watermark, and subtracting (3) said distorted image from the suspect image.

2.   A method as claimed in claim 1, wherein the suspect image is one of a sequence of images, the method comprising the steps of estimating motion (21) between the suspect image and another image (22) of said sequence to obtain motion vectors, the distorted image being obtained by applying motion compensation (23) to said other image using said motion vectors.

3.   A method as claimed in claim 2, further comprising the step of randomly modifying (24) said motion vectors at least in image areas in which the motion vectors are zero or identical.

4.   A method as claimed in claim 1, wherein the suspect image is divided into a plurality of image regions (33), the distorted image being obtained by differently shifting (31) said regions.

5.   A method as claimed in claim 1, in which the suspect image is a block-based predictively encoded image of a motion video signal comprising a residual image and motion vectors, characterized in that said residual image constitutes the pre-processed image.

6.   A method as claimed in claim 1, wherein said step of deriving the distorted image comprises subjecting the suspect image to a non-linear filter operation.

7.   A method as claimed in claim 6, wherein said non-linear filter is a median filter.

8.   A device for detecting a watermark in a suspect image, comprising means (2,3) for pre-processing the suspect image, means (11,12) for determining the amount of correlation between the pre-processed image and the watermark, and means (13) for generating a watermark detection signal in dependence upon said amount of correlation, characterized in that said means (2) for pre-processing comprises means (2) arranged to derive from the suspect image a distorted but resembling image which has less correlation with the watermark, and means (3) for subtracting said distorted image from the suspect image.
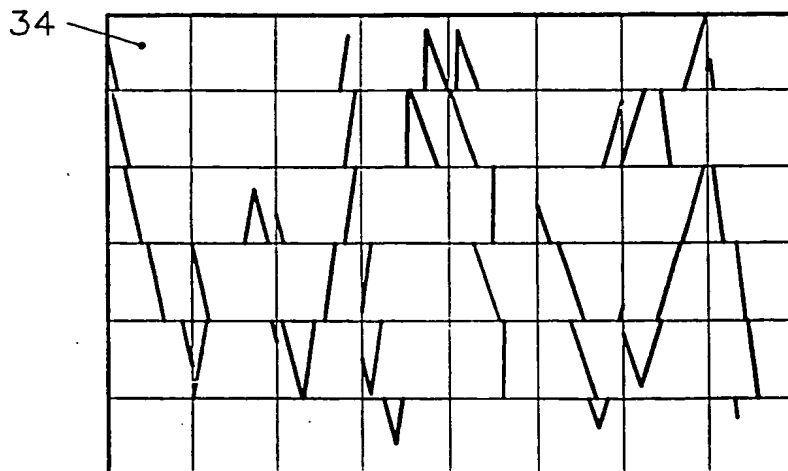
1/3
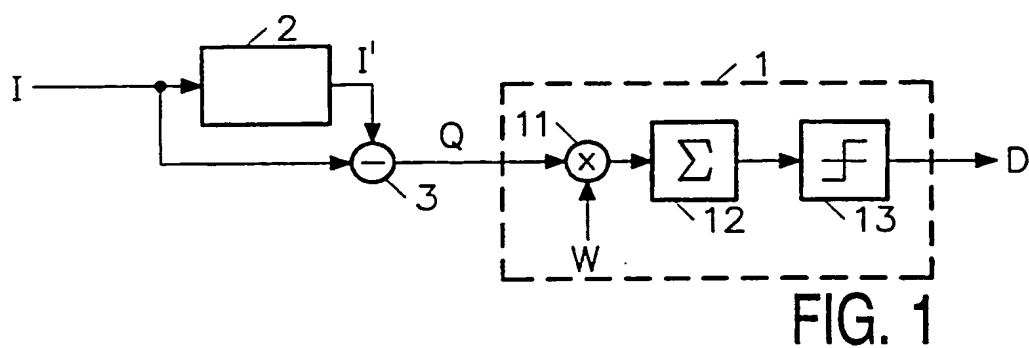
FIG. 1
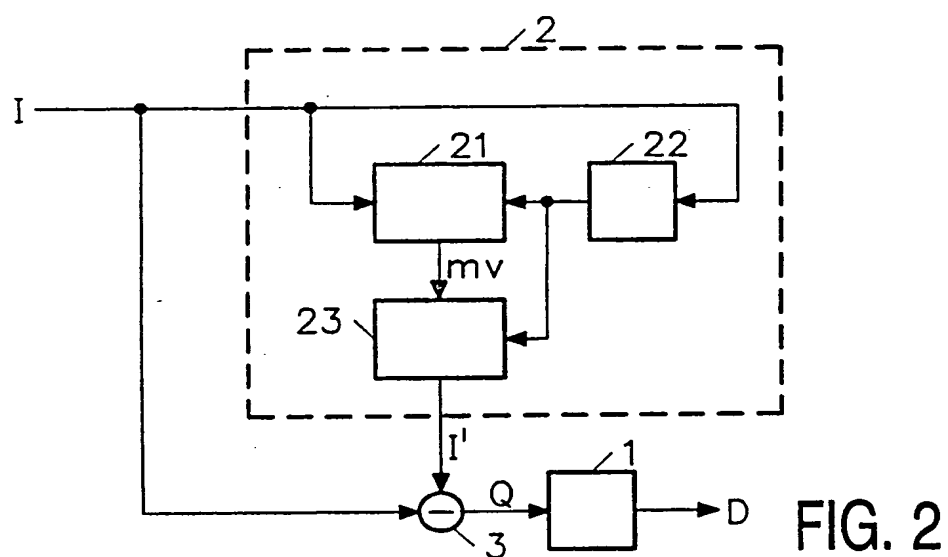
FIG. 2
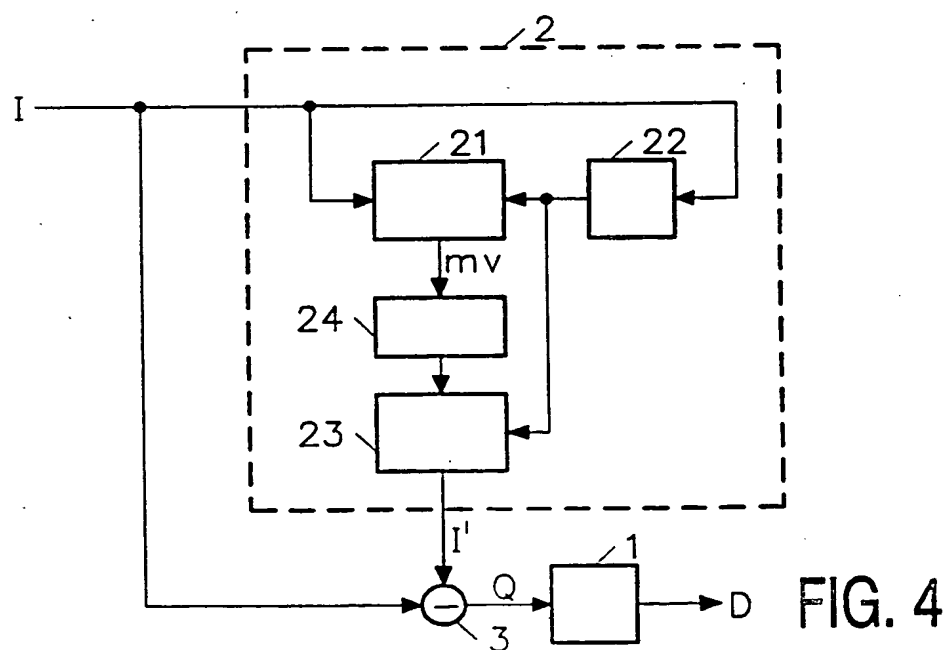
FIG. 4
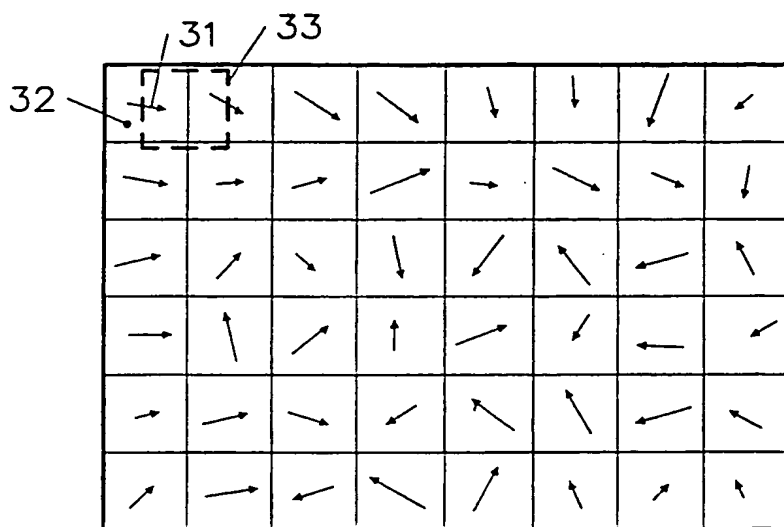
FIG. 3A
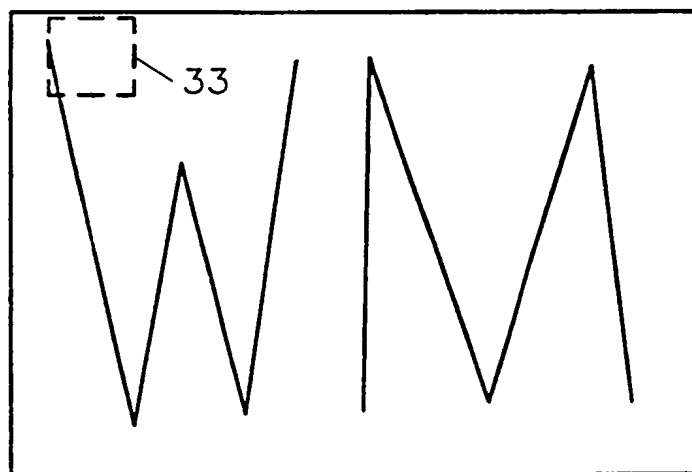
FIG. 3B

FIG. 3C
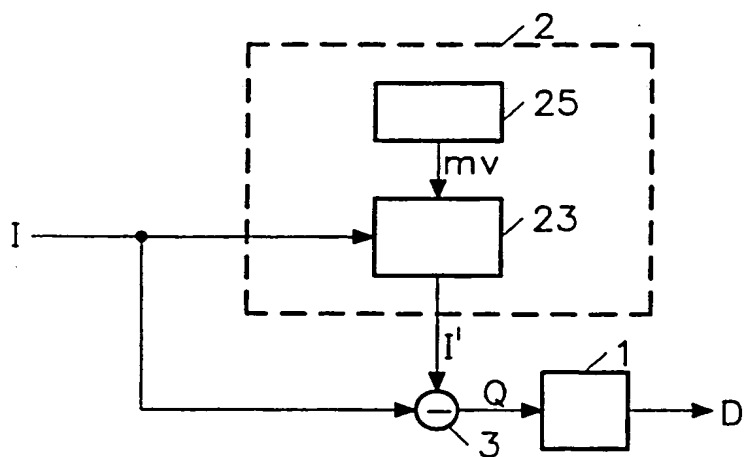
FIG. 5
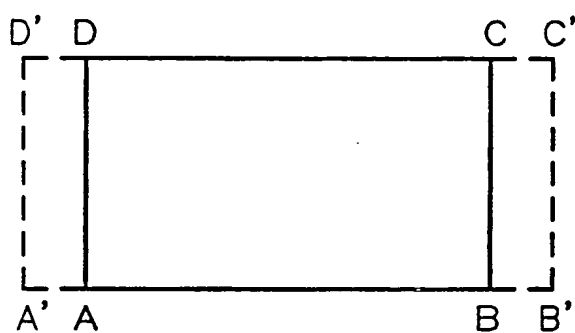
FIG. 6A
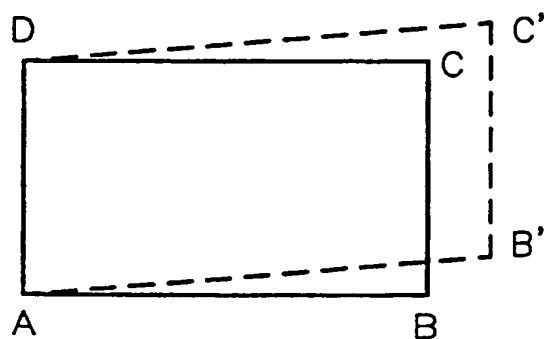
FIG. 6B
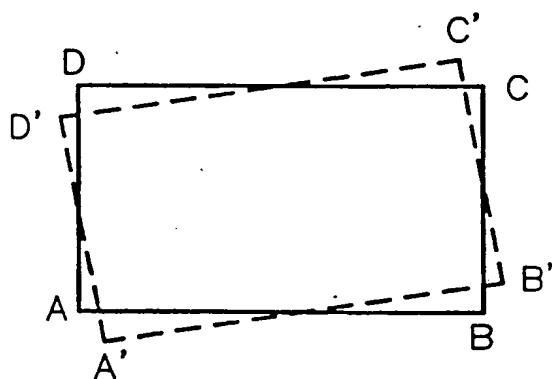
FIG. 6C

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7   G07D7/00   H04N1/32

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7   G07D   H04N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 748 783 A (RHOADS GEOFFREY B) 5 May 1998 (1998-05-05) claim 1; figure 24	1-8
A	EP 0 828 372 A (NIPPON ELECTRIC CO) 11 March 1998 (1998-03-11) claim 1; figure 4	1-8
A	EP 0 777 197 A (EASTMAN KODAK CO) 4 June 1997 (1997-06-04) claim 1; figure 1	1-8
A	WO 98 03014 A (PHILIPS ELECTRONICS NV ;PHILIPS NORDEN AB (SE)) 22 January 1998 (1998-01-22) cited in the application claim 1; figure 1	1-8

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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Date of the actual completion of the international search	Date of mailing of the international search report
15 December 1999	12/01/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Kirsten, K

Form PCT/ISA/210 (second sheet) (July 1992)

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INTERNATIONAL SEARCH REPORT

Information on patent family members

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